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ANOMALOUS Z^o DECAY AND A STRONGER COUPLED HIGGS BOSON

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ABSTRACT: We investigate the possibility that a Higgs boson with a stronger coupling to Z^o and a dominant decay in two photons could explain the anomalous Z^o decays.

1. Introduction. The recent discovery of the $W^{\pm}$ and Z^o vector bosons at the CERN SPS p-$\bar{p}$ collider[1][2] seems to confirm the properties predicted by the standard model of Glashow-Weinberg-Salam[3], in particular the values for the masses and the ρ parameter. Nevertheless, among the seventeen Z^o events observed by the UA1 and UA2 Collaborations, there are three of them with a hard photon accompanying the leptonic pair. This number of anomalous events (~ 18%) cannot be explained by a bremsstrahlung process[4]. However we may not yet discard the possibility that such a large ratio might disappear when more data becomes available.

Several authors have proposed models[5] in order to explain the anomalous Z^o decays. However, as was pointed by Barger, Baer and Hagiwara[6], none of these alternative models provides a satisfactory explanation of the observed events.

Up till now the experimental resolution is not capable of distinguishing if the anomalous events contain one or two unresolved photons, such as from the $\gamma\gamma$ decay of a π^o or an η meson. In this letter we investigate the latter possibility, by supposing that the two photons come from the radiative decay of a light Higgs particle with an enhanced coupling to the vector boson:

$$Z^o \rightarrow \ell^+\ell^- + H \quad (H \rightarrow \gamma\gamma) \tag{1}$$

A Higgs particle with similar properties was proposed by Einhorn[7] in another framework. The "Higgs Remnant" of Einhorn has a much stronger coupling to the vector boson than the standard model Higgs of comparable mass and has a dominant decay in two photons, if $M_H < M_Z$.

The ratio of the decay rates of $Z^0 \to \ell^+\ell^-(\gamma\gamma)$ to $Z^0 \to \ell^+\ell^-$, in our case, is given by:

$$R \equiv \frac{\Gamma(Z^0 \to \ell^+\ell^-(\gamma\gamma))}{\Gamma(Z^0 \to \ell^+\ell^-)} = \frac{\Gamma(Z^0 \to \ell^+\ell^- H) . BR(H \to \gamma\gamma)}{\Gamma(Z^0 \to \ell^+\ell^-)} \qquad (2)$$

If we take into account the experimental value of this ratio, and optimistically assume that $BR(H \to \gamma\gamma) \sim 1$, we can write:

$$R \simeq \frac{\Gamma(Z^0 \to \ell^+\ell^- H)}{\Gamma(Z^0 \to \ell^+\ell^-)} = \frac{3}{17} \qquad (3)$$

2. Evaluation of the decay rate $\Gamma(Z^0 \to \ell^+\ell^- H)$.

We shall assume the coupling of the Z^0 to the leptonic pair given by the standard model. For the vertex ZZH, we write:

$$V_{\mu\nu}^{ZZH} = g_{\mu\nu} \cdot f_H \qquad (4)$$

where the value of f_H, the strength of the Higgs coupling to Z^0, will be fixed by the experimental rate of anomalous events. The double-differential distribution in the reduced energies of the leptonic pair, in the rest frame of the decaying Z^0 is given by[8]:

$$\frac{d^2\Gamma}{dx_+dx_-} = \frac{g^2(1 - 4\mathrm{sen}^2\theta_W + 8\mathrm{sen}^4\theta_W)}{3072\,\pi^3 . M_Z . \cos^2\theta_W} \cdot f_H^2 \cdot F(x_+,x_-;\delta^2) \qquad (5)$$

where we have defined:

$$F(x_+,x_-;\delta^2) = \frac{(x_+ + x_- + x_+ . x_- + \delta^2 - 1)}{(x_+ + x_- + \delta^2 - 2)^2}, \qquad (6)$$

with the reduced energies of the massless leptons given by:

$$x_\pm = \frac{2E_\pm}{M_Z} \qquad (7)$$

and, the reduced mass of the Higgs boson:

$$\delta = \frac{M_H}{M_Z} \qquad (8)$$

The energy-momentum conservation determines the Dalitz contour in the $x_+ - x_-$ plane:

$$x_+x_- \geq x_+ + x_- + \delta^2 - 1 \geq 0 \qquad (9)$$

This relation enables us to integrate (6) to obtain:

$$F(\delta^2) = \int F(x_+,x_-;\delta^2)\,dx_+dx_- =$$

$$= (1-\delta^2)\left[\frac{1}{12}(1-\delta^2)(1+2\delta^2) + \delta^2 - 4\right] + \frac{1}{4}\left[2\delta^2 - (2-\delta^2)^2\right]\ell n\,\delta^2 -$$

$$- 2\alpha\left[\arctan\alpha - \arctan\beta\right] + \frac{\delta^4}{2\alpha^3}\left[\arctan\frac{1}{\alpha} - \arctan\frac{1}{\beta}\right] \qquad (10)$$

where:

$$\alpha \equiv \frac{\delta}{\sqrt{4-\delta^2}} \qquad \text{and} \qquad \beta \equiv \frac{(2-\delta^2)}{\delta\sqrt{4-\delta^2}} \qquad (11)$$

The behavior of $F(\delta^2)$ is given in Figure 1.

Then we obtain, for the decay rate:

$$\Gamma(Z^0 \to \ell^+\ell^- H) = \frac{g^2(1 - 4\mathrm{sen}^2\theta_W + 8\mathrm{sen}^4\theta_W)}{3072\,\pi^3 M_Z \cos^2\theta_W} \cdot f_H^2 \cdot F(\delta^2) \qquad (12)$$

Since the decay rate of Z^o in a leptonic pair in the standard model is:

$$\Gamma(Z^o \to \ell^+\ell^-) = \frac{g^2 M_Z (1 - 4\text{sen}^2\theta_W + 8\text{sen}^4\theta_W)}{96\pi \cos^2\theta_W} \tag{13}$$

we can write the ratio (2) as:

$$R = \frac{f_H^2}{32\pi^2 M_Z^2} \cdot F(\delta^2) = \frac{3}{17} \tag{14}$$

Therefore, we can estimate the strength of the Z^o coupling to the Higgs boson:

$$f_H = \pi M_Z \left[\frac{96}{17\, F(\delta^2)}\right]^{1/2} \tag{15}$$

Figure 2 shows the data of UA1 and UA2 Collaborations and the contour curves for different values of $F(x_+, x_-; \delta^2)$. We have fixed $\delta = 0{,}07$ in order to include experimental data in the physical region. In this case, we can see that (15) is just ~7 times the value expected by the standard model ($2^{5/4} M_Z^2 \sqrt{G_F}$). Figure 3 shows the invariant mass distribution of the leptonic pair. We hope that future data approach the most probable regions of the Dalitz plot and invariant mas distribution, so that our proposal might be confirmed.

3. Conclusion. Our suggestion can be tested at PETRA, searching for $e^+e^- \to \ell^+\ell^-\gamma\gamma$ events above the Z^o threshold. We may expect that the Higgs coupling to charged

fermions be sufficiently suppressed in order not to alter the recent results obtained by CELLO Collaboration[9]. The absence of anomalous events in the $W^\pm$ decays[10] can be explained if we assume the standard coupling of the Higgs to W bosons.

We think that only future data with better statistics will enable us to decide whether we are facing a new physics or whether the standard model can explain[11] the anomalous Z^o decays.

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FIGURE CAPTIONS

Figure 1 - Behavior of $F(\delta^2)$ (10) as a function of $\delta = \frac{M_H}{M_Z}$.

Figure 2 - Physical region in the $x_+ - x_-$ plane for the process $Z^o \to \ell^+\ell^- H$ with $\delta = 0,07$ and the data points of Ref. (2). The dashed lines represent the contour curves of $F(x_+, x_-; \delta^2)$ (6).

Figure 3 - Invariant mass distribution of the leptonic pair for the process $Z^o \to \ell^+\ell^- H$.

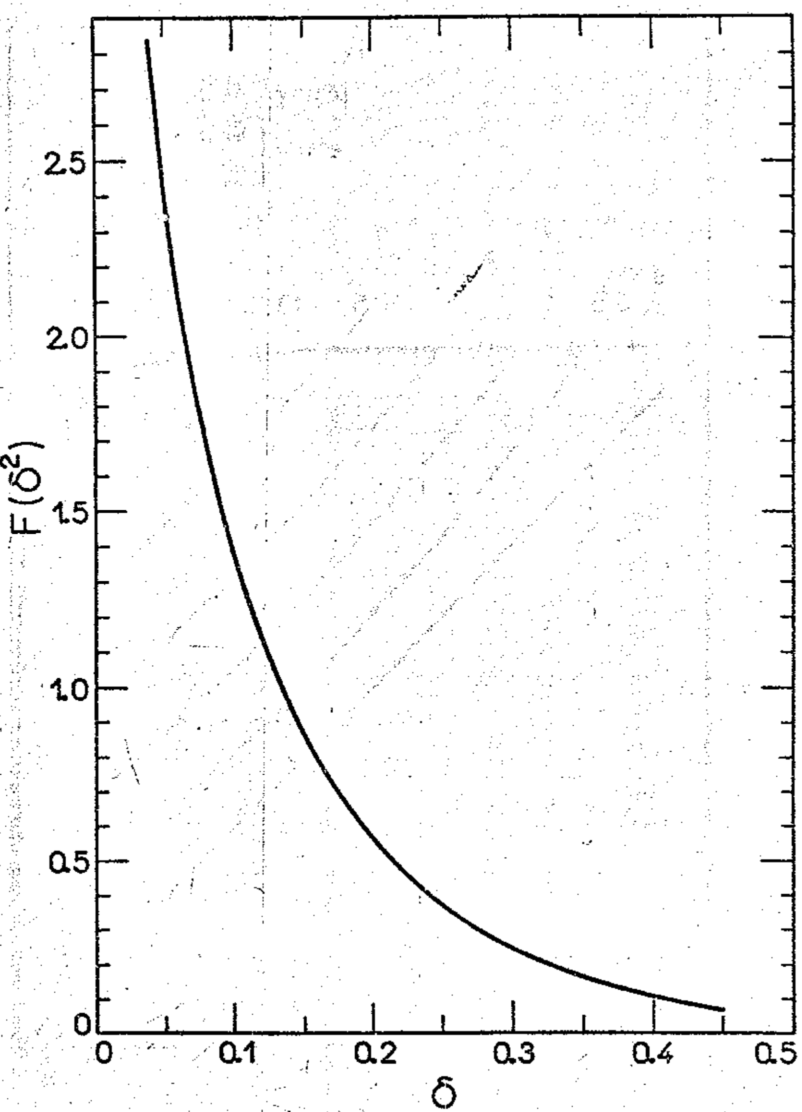

FIGURE 1

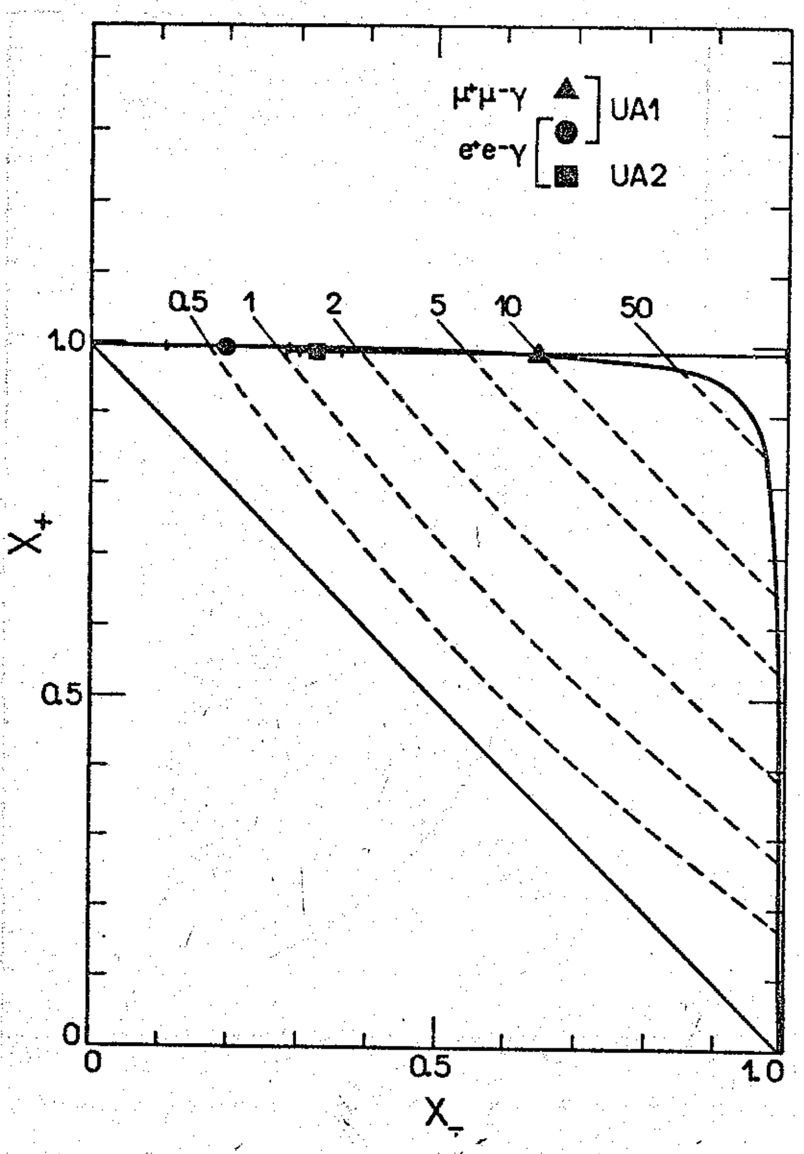

FIGURE 2

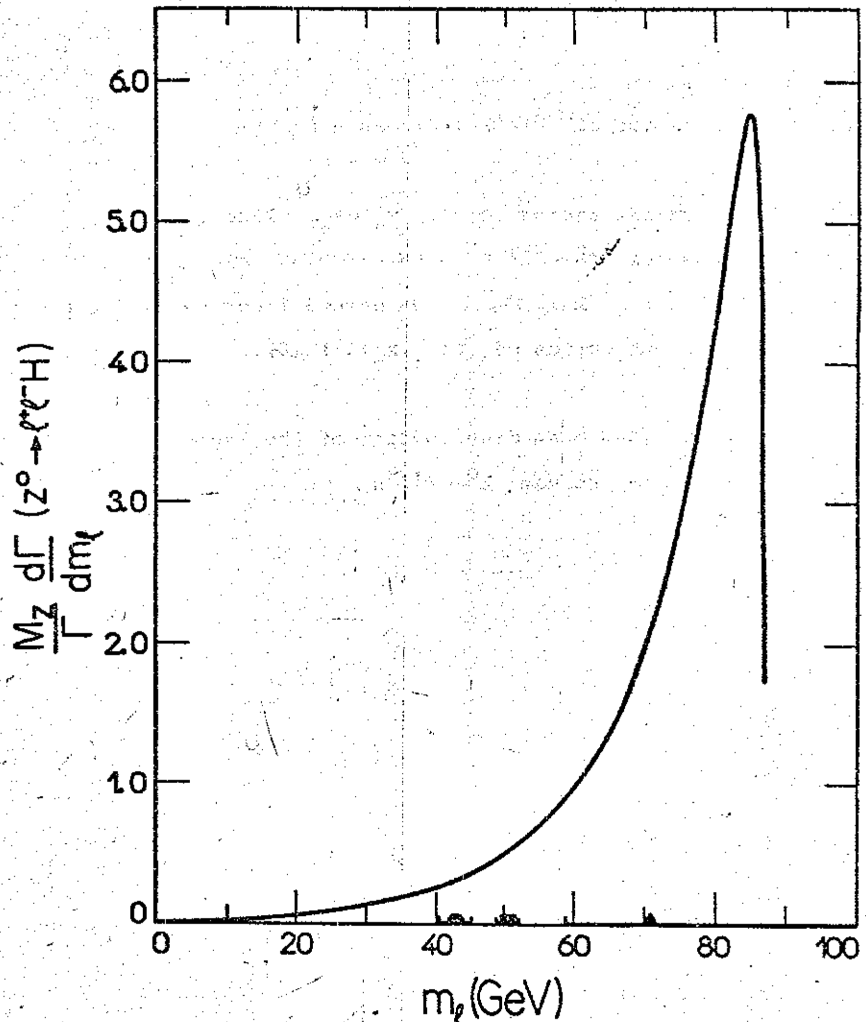

FIGURE 3